Zero Emission Cargo Transport II

San Pedro Bay Ports Hybrid & Fuel Cell Electric Vehicle Project

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South Coast Air Quality Management District

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(This presentation does not contain any proprietary, confidential, or otherwise restricted information) [Project ID # GI158]

ZECT II Overview

Timeline

- Project Award: 10/1/14
- Contractor Kickoff: 12/16/15
- Project Completion: 9/30/19

Contractors & Projects

- BAE/CTE - Fuel cell range extended drayage truck
- TransPower - Fuel cell range extended drayage truck
- U.S. Hybrid - Fuel cell powered drayage truck
- BAE/GTI - CNG hybrid with catenary accessibility
- Hydrogenics – Fuel cell range extended drayage truck

Barriers & Challenges

- Fueling Infrastructure: Availability and location
- Costs: Fuel Cells, batteries and infrastructure
- System Integration: Safe and efficient deployment of the technology

Budget

- DoE: $10,000,000
- Funding partners: $7,467,473
- Contractors: $3,075,841

Total Cost:$20,543,314

Relevance: Goals & Objectives

- **Goals:**
  - Reduce criteria pollutants, GHG's and petroleum consumption in South Coast Air Basin
  - Accelerate introduction of electric transportation technologies in cargo transport sector
- **Objectives:**
  - Develop hydrogen fuel cell and CNG hybrid technologies
  - Employ Vehicle Integrators to quickly deploy trucks
  - Employ major truck OEM's which have design, engineering, manufacturing and marketing capability
- **Impact:**
  - Vehicle Integrators show proof of concept and challenges early in the project
  - OEM's refine vehicles to higher TRL – If feasible they are able to manufacture and market trucks in large volumes




Relevance: Approach & Strategy

- **Approach:**
  - Require contractors to have experience with fuel cell or battery electric truck and bus development
  - Require contractors to partner with a major OEM
- **Strategy:**
  - Leverage previous and ongoing project's vehicle technologies
  - Use American Fuel Cell Bus technology partners
- **Impact:**
  - BAE and Kenworth reduced development time and cost on both CNG Hybrid and Fuel Cell trucks by sharing components, systems hardware, software and reducing integration complexity with shared platforms
  - Development and test facilities at BAE and Kenworth far exceed that of vehicle integrators




Relevance: Barriers & Challenges

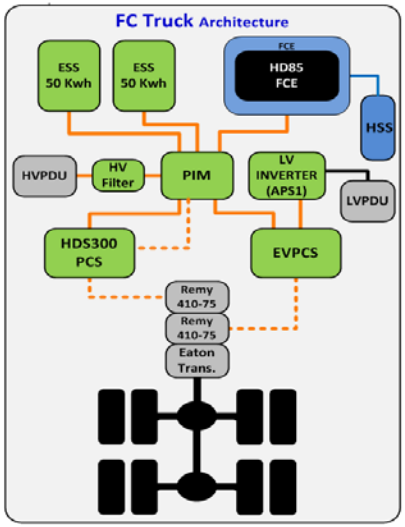
- **Barrier:**
  - Hydrogen Fueling Infrastructure: Availability and location
  - Heavy duty hydrogen powered vehicles cannot use light duty vehicle stations
  - Transit bus stations are not accessible
- **Solution:**
  - Air Products will provide a portable onsite refueling from local refinery
  - Tube trailer with quick fill dispensers for convenient refueling at fleet operators site
  - Permanent heavy duty fueling station being considered by SCAQMD & partners
- **Impact:**
  - Convenient, dependable, and efficient onsite refueling for the demonstration period
  - Researching permanent site near the ports

- **Challenge:**
  - System Integration: Safe and efficient deployment of the technology
- **Solution:**
  - DOE and Eaton facilitated the transfer of a Ballard fuel cell from a previously completed project to SCAQMD for use by its sub recipient and their contractor BAE Systems
- **Impact:**
  - BAE will utilize the fuel cell in their laboratory for system development and to simulate anomalies in the field with the Kenworth truck and quickly turn around solutions
  - BAE and Kenworth will be able to reduce down time and save on development costs

Fuel Cell Drayage Truck

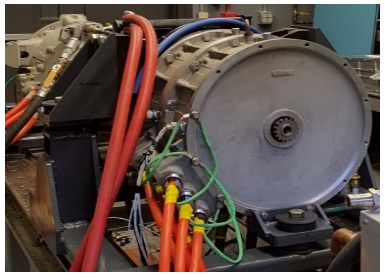
Technical Progress
Propulsion System

- ✓ Completed architecture for the HybriDrive™ propulsion system
- ✓ Simulated propulsion system model on TTSI, TIAX and NREL drive cycles
- ✓ BAE handed off propulsion system solid models to Kenworth for integration into truck design
- ✓ Software, firmware, and control laws for propulsion system are under active development



Technical Progress
Integration & Testing

- ✓ Dual traction motors and transmission mounted on dynamometer for testing
- ✓ Test shed setup for fuel cell testing
- ✓ An additional HD85 fuel cell in process of being transferred from a different DOE program to accelerate system testing
- ✓ A lab has been setup to test the battery packs
- ✓ Propulsion Design and Test plan have passed critical design review



Traction Motor Test Stand

Fuel Cell Test Shed

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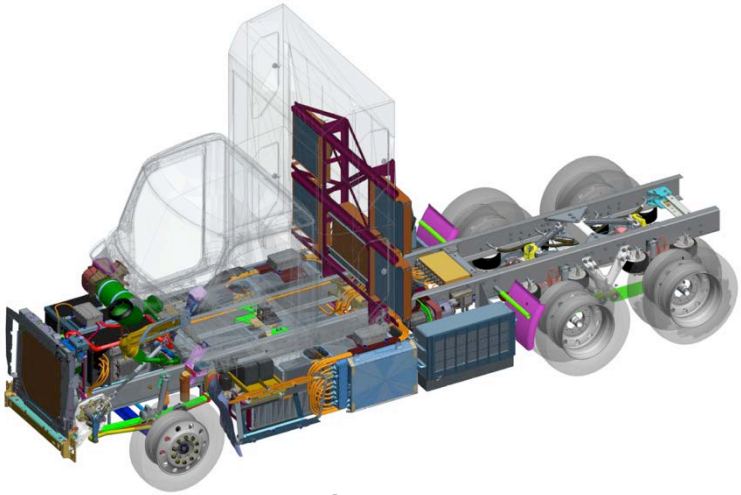
INSPIRED WORK

South Coast AQMD

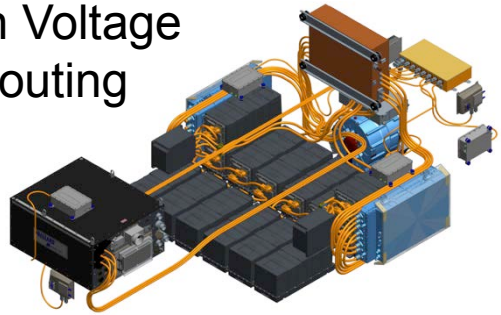
Technical Progress

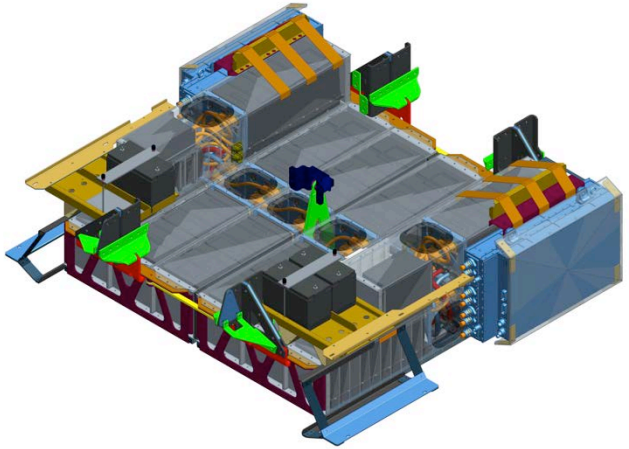
- ✓ Solid models for BAE HybriDrive™, Ballard HD85 fuel cell, high voltage battery pack and hydrogen storage system have been fitted to the T680 truck model
- ✓ Custom electric auxiliary systems including air conditioning compressor, brake air compressor, and power steering system design complete
- ✓ Combined 100 kWh XALT battery pack enclosure with integrated cooling and center pivot to accommodate frame twist designed
- ✓ Multiple cooling loop designs for power electronics, battery pack, traction motors, and fuel cell complete
- ✓ Ballard has approved Kenworth's fuel cell integration design
- ✓ Hydrogen fuel cell drayage truck design passed critical design review



H2 Fuel Cell Truck Layout

High Voltage Routing



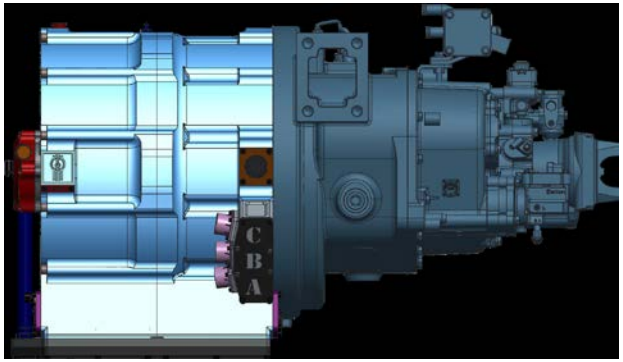


Battery Pack Assembly

Technical Progress

- ✓ Kenworth T680 donor vehicle delivered
- ✓ Custom electric AC compressor, DC-DC converter and brake air compressor delivered
- ✓ BAE power electronics components are on order
- ✓ Ballard HD85 fuel cell delivered in April, 2017
- ✓ Integrated oil cooled dual traction motor system on order – provides similar performance to diesel when used with Eaton 4 speed automatic transmission
- ✓ Hydrogen storage system with at least 25kg usable capacity on order
- ✓ Completed pre-production review
- ✓ Truck conversion began April 2017

Kenworth T680 Delivered



Traction Motor/Transmission Assembly

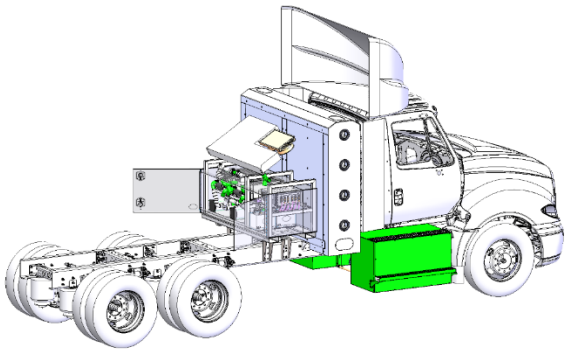
Fuel Cell Drayage Truck

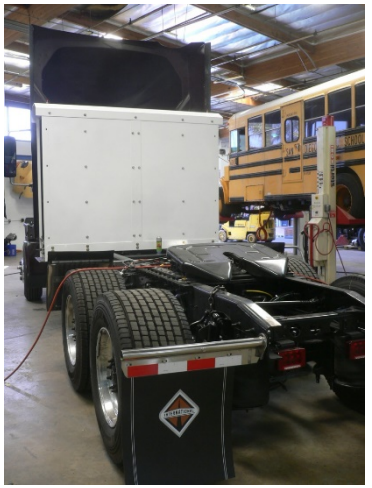
Proposed Truck With APU

- Drop battery energy storage to 120kWh (80%DOD)
- Add gaseous storage (17 kg H2), FC Range Extender
- Increase range to 150 miles

Vehicle Packaging

Major components are on the truck, including motive drive system, power conversion/accessories system and fuel system.





Technical Progress

Battery Testing

- Battery modules have been fabricated and tested using the AV900, and are awaiting the pack frames and BMS for final assembly. Data shows the modules fully charged and balanced.

Hardware In-the-loop Testing

- Software development testing has been initiated using the benchtop fuel cell / DC-DC conversion system.

Technical Progress

Fuel Cell System Testing

- Structural fabrication of the Fuel Cell Assembly is complete
- Major components were installed on vehicle and wired in April

Spring-Summer Schedule

1. Completion and test of battery, installed on truck
2. Completion and test of Fuel Cell Auxiliary Power Pack (FCAPP)
3. Install FCAPP on truck, test and commission truck
4. Truck to be available for ACT Conference
5. Road test, evaluation of fuel cell hybrid truck
    1. 500 mile shakedown
    2. Roadability (speed, acceleration, hill climb records)
    3. Range as bobtail, with trailer.
6. Fabrication of second truck, with fuel system, FCAPP
7. Delivery of first truck to customer, initial training
8. Delivery of second truck

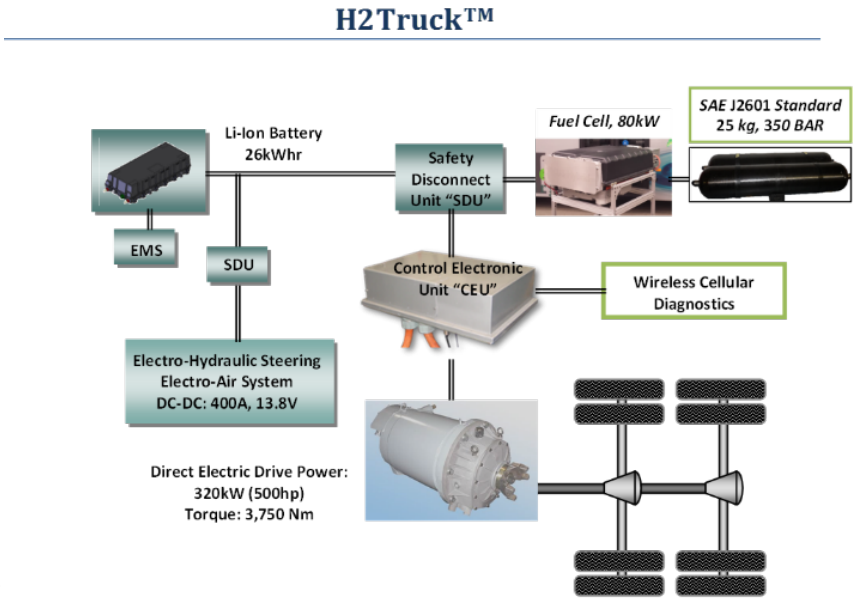
Fuel Cell Drayage Truck

Technical Progress
Fuel Cell Testing

- Completed the 80kW fuel Cell with integrated high efficiency isolated dc-dc converter, tested at the test-stand in South Windsor facility.

Technical Progress
Design/Integration

- Truck has been partially integrated



Fuel Cell Electric Class-8 Truck Powertrain System Configuration

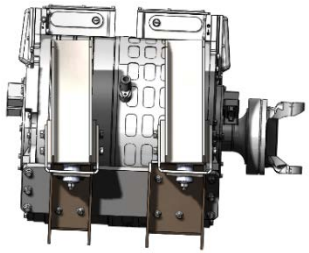
Technical Progress

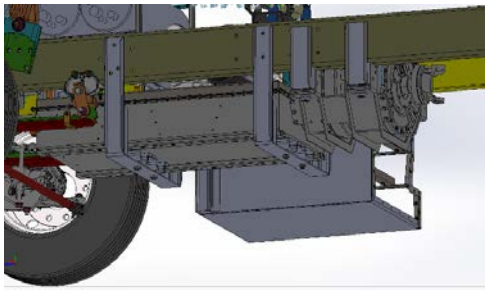
Hydrogen Storage

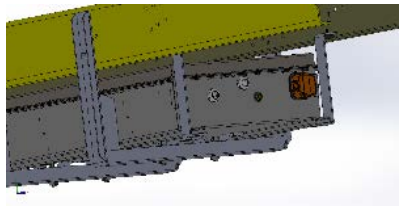
- Completed the design, procurement and installation of the H2 tanks in collaboration with Agility with after sales support.

Auxiliary Systems

- Battery, drive system and fuel cell vehicle packaging design completed.
- Auxiliary system designed and partially integrated



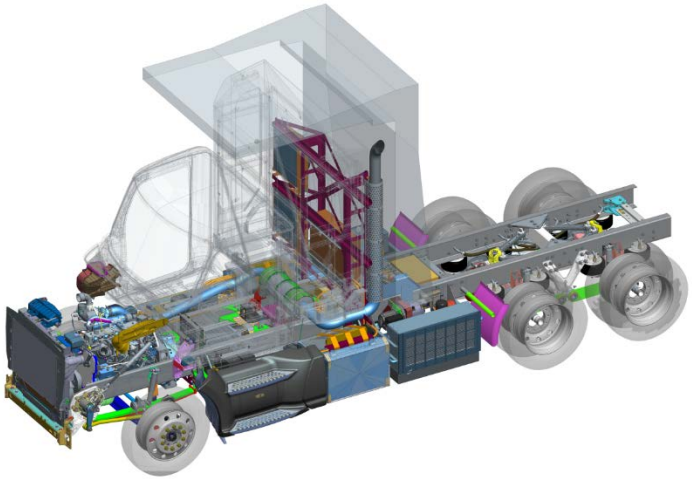




CNG Hybrid Electric Drayage Truck

Production Kenworth T680 Modifications

- Kenworth T680 Day-cab
- Cummins Westport L9N Near-Zero engine
- BAE Generator, Propulsion Control Systems, Power Interface Module, 650V to 24V inverter
- Custom Dual-Remy ACTM
- XALT 100kWh battery packs
- Custom 650V A/C compressor, Air compressor, power steering
- Multiple cooling loops



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Technical Progress

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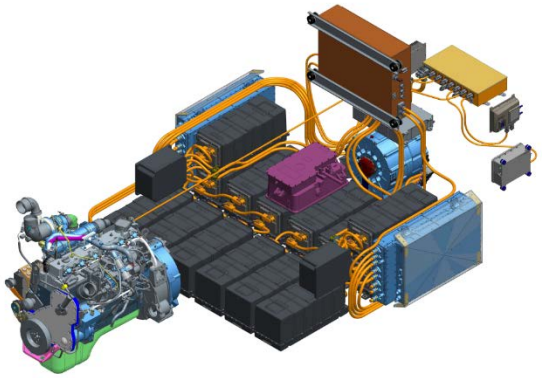
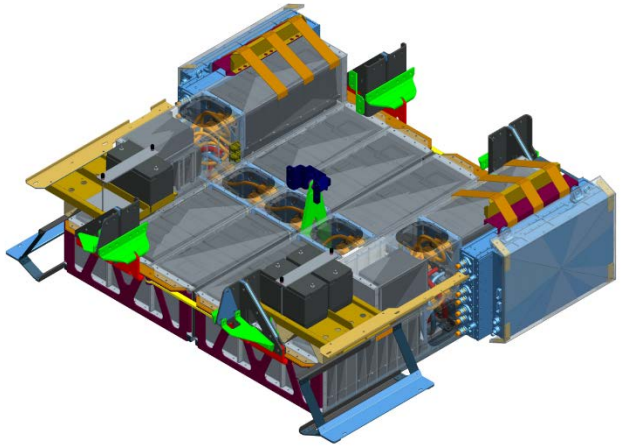
Propulsion System

- Cummins Westport L9N Near-Zero CNG genset
- 100kWh XALT battery packs
- BAE High Voltage control electronics
- Dual Remy HVH410 ACTM
- 650V A/C compressor, air compressor, and power steering pump



Energy Storage

- 100 kWh XALT battery storage system
- 14 XALT battery packs per truck
- High Voltage wiring and cooling plumbing done within the ESS
- Components attached to ESS frame
- Center pivot to accommodate frame twist



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Range Extender Engine

- Certified to CARB's Lowest Optional Low NOx Standard (0.02g/bhp-hr)
- 4 cycle, spark ignited, in-line 6 cylinder, turbocharged, CAC
- Displacement - 8.9 Litre
- L9N Near-Zero CNG genset introduced in 2016
- Exceeds 2017 EPA GHG requirements
- 2018 On-board Diagnostic (OBD) compliant
- Dedicated 100% natural gas engine
- Peak rating: 320 hp, 1000 lb-ft

L9N™
NEAR ZERO

Cummins Westport CNG Engine

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Fuel Cell Drayage Truck

Project Goals

- Demonstrate Fuel Cell Drayage Truck in a Daimler Freightliner chassis
- Integrate Hydrogenics fuel cell with Siemens' electric drive into vehicle
- Demonstrate in ports of Long Beach, Port of LA, collect and analyze data

Truck Specifications

Item	Target Specification
Chassis	Daimler Freightliner Cascadia Day Cab
GVWR	80,000 lbs
Fuel Cell Power System	Hydrogenics CelerityPlus
Electric Drive	Siemens ELFA PM Motor
Battery	ACTIA100 kWh
System Voltage	650 V
Hydrogen Storage	30 kg @ 350 bar
Refuel Time	10-15 minutes
Expected Range	150-200 mi

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Technical Progress

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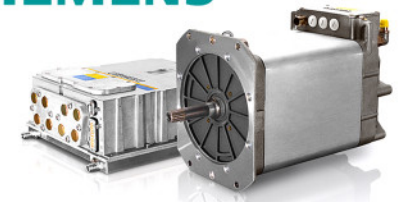
CEC & DOE Project Status

- ✓ Design and Procurement Phase 40% Complete
- ✓ Developed Guiding Document for design, BOM and build process
- ✓ Chassis Selection and Optimization:
  - ✓ Daimler provided engineering support
  - ✓ Obtained all CAD drawings and electrical schematic for truck design
- ✓ Completion of component selections for fuel tanks and thermal management
- ✓ Evaluation of multiple vehicle components layout:
  - ✓ Evaluated packaging of main components
  - ✓ Constraints include weight distribution, aesthetics, serviceability and capacity
- ✓ Contract for DOE ZECT project in process

DAIMLER

SIEMENS



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Research: Commercialization

- **CALSTART surveyed 1,398 port drayage fleets in the Clean Truck Program to gauge interest in advanced technology trucks, identify trends and market barriers**
  - ❖ Only a few port drayage fleets have experience with LNG and CNG trucks. Experience with other technology is limited to Transpower Battery Electric trucks
  - ❖ Some fleets are early adopters of advanced technology trucks; a large majority are interested but not currently using them; some appear reluctant to try them
- **A large number of port drayage trucks will need to be replaced in the next 5 years**
  - ❖ Original Clean Truck Program trucks are nearing the end of life
  - ❖ Largest drayage fleets should be target for advanced technology truck deployments
- **OEMs do not define a specific "port drayage" market segment and Class 8 truck tractors are specified to be versatile**
  - ❖ Advanced trucks must be "all-purpose" to be most successful




Response to Reviewers Comments

- (Q-1,R-1) …The reviewer would have liked for the project team to have included an analysis of where the H2 will come from in the future. If it comes from CH4, there is not much GHG benefit. The basic idea of adding on something expensive to another expensive technology is not likely to be very favorable on economic grounds, either. The reviewer would have added a comparative economic assessment to the scope of the project. In California state funded hydrogen stations (currently CA funds ~ +90% of H2 stations) must provide 33% of H2 dispensed from renewables. Currently there is a concerted effort by state and local agencies to fund renewable generation of H2. SCAQMD teamed up with APCI, DOE & Fuel Cell Energy for Tri-generation of 100% renewable H2 from digester gas, CSULA H2 station's electrolyzer produces 100% renewable H2 with green electrons from LADWP hydroelectric power. We are also investigating wind & solar to gas.

  An economic analysis of the technology is premature at this point since most of the costs are one time engineering and development costs. The two major components - batteries and fuel cells costs are dropping and will continue to fall as production of light duty EV's & FCEV's ramps up and are brought to market.

ZECT II Summary

- BAE and Kenworth are making progress on vehicle design, analysis, equipment purchase and integration work
- Hydrogenics replaced International Rectifier with a fuel cell range extended drayage truck – CEC project and DOE contract in progress
- Temporary hydrogen refueling secured for demonstration & permanent heavy duty refueling being investigated
- TransPower and U.S. Hybrid trucks conducting tests in May/June
- U.S. Hybrid truck and hydrogen supply ready for summer demonstration in July/August
- Future Research: Expand Commercialization Plan & Scenario Model (subject to funding levels)
  - ❖ Enable adoption simulation input and provide outputs that quantify emissions savings and vehicle counts